Spatial Distribution of Soil Carbon and Nitrogen Pools under Grazed Tall Fescue

A. J. Franzluebbers,* J. A. Stuedemann, and H. H. Schomberg

ABSTRACT

Cattle (*Bos taurus*) behavior may be an important variable controlling the spatial distribution of soil C and N pools in long-term, grazed pastures. Shade and water sources are more frequented areas of a pasture that can also serve as camping areas where excreta are deposited. We sampled a Cecil sandy loam (fine, kaolinitic, thermic Typic Kanhapludult) under tall fescue (*Festuca arundinacea* Schreb.) at distances of 1, 10, 30, 50, and 80 m from permanent shade or water sources at the end of 8 and 15 yr of grazing. To a depth of 75 mm, soil bulk density was 1.15 Mg m^{-3} at 1 m and averaged 1.00 Mg m^{-3} at other distances from shade or water. To a depth of 300 mm, soil organic C was 4.6 kg m^{-2} at 1 m, 4.3 kg m^{-2} at 10 m, and ≈4.0 kg m^{-2} at distances of 30, 50, and 80 m from shade or water. Particulate organic C averaged 1.53 kg m^{-2} at distances of 1, 10, and 30 m and 1.30 kg m^{-2} at distances of 50 and 80 m from shade or water. Soil microbial biomass C, basal soil respiration, and net potential N mineralization were also greater nearer shade or water than farther away. Although lateral distribution effects were most dramatic at a depth of 0 to 25 mm, similar effects were observed even at a depth of 150 to 300 mm. Long-term cattle grazing in relatively small paddocks (0.7–0.8 ha) with permanent shade and water sources resulted in significant lateral and vertical changes in soil organic C and N pools.

Animals grazing in confined paddocks do not uniformly consume forage, nor do they uniformly defecate and urinate. Long-term, lateral redistribution of nutrients via animal behavior has not received a great deal of attention, although information from short-term grazing studies indicates that available P and K can be concentrated near shade and watering areas (Wilkinson et al., 1989; West et al., 1989; Mathews et al., 1994). Concentration of plant-available nutrients in excess of plant demand near shade and watering areas could accelerate gaseous and leaching losses, thereby increasing the risk of environmental pollution. Redistribution of nutrients within a paddock also suggests a need for variable fertilizer requirements, depending on the location of shade and watering areas.

Interactions between soil nutrient availability and soil microbial processes are important in differentiating between potential and actual losses of nutrients. Accumulation of soil organic matter under grassland is an important process necessary for development of diverse soil microbial communities capable of cycling and sequestering soil nutrients. Lateral distribution of soil organic matter in grazed paddocks has not been investigated in great detail, but is likely to be significant because of greater fecal deposition and less complete grazing near shade and water sources (Wilkinson et al., 1989; West et al., 1989). A quantitative description of soil organic C and N pools (i.e., total, passive, and active) within grazed paddocks is necessary to partition nutrients along a gradient ranging from relatively immobile organic forms to highly labile inorganic forms.

Our objective was to determine the lateral and vertical distributions of soil organic C and N pools (i.e., total, particulate, microbial biomass, and mineralizable) in long-term (i.e., 8 and 15 yr), grazed tall fescue pastures.

MATERIALS AND METHODS

A total of 12 'Kentucky-31' tall fescue paddocks varying in stand age (8 [$n = 4$] and 15 [$n = 8$] yr), fertilization (134-15-56 [$n = 4$] and 336-37-139 [$n = 8$]) kg N-P-K ha^{-1} yr^{-1}), and endophyte infection (low 0–29% [$n = 6$] and high 65–94% [$n = 6$]) were sampled near Watkinsville, GA (33°62′ N, 83°25′ W), on gently sloping (2–4%) Cecil sandy loam. Mean annual temperature is 16.5°C, precipitation is 1250 mm, and pan evaporation is 1560 mm.

Paddocks were 0.7 to 0.8 ha with permanent shade and water sources placed ≈20 m apart along an edge with higher elevation. Paddock design was described in Wilkinson et al. (1989). All paddocks were grazed with Angus cattle each year following establishment, primarily in spring and autumn.

Soil samples were collected at depths of 0 to 25, 25 to 75, 75 to 150, and 150 to 300 mm at distances of 1, 10, 30, 50, and 80 m from shade or water sources during a 3-wk period in late January to early February 1997. Tall fescue was green at time of sampling, but growth was minimal. Eight cores (41-mm diam.) separated by 8 to 15 m in a semicircle pattern around shade and water sources were composited within each depth and distance. Soil was oven dried (55°C, 48 h), weighed, and crushed to pass a screen (4.75-mm openings) to partially homogenize samples and remove stones (<1% of weight). Bulk density was calculated from the oven-dried soil weight and coring device volume. Soil for subsequent analyses was stored dried for ≈1 yr. A subsample was ground to a fine powder with a ball mill for 5 min and analyzed for total C and N by dry combustion (Leco CNS-2000, St. Joseph, MI)[1]. It was assumed that total C was equivalent to organic C, because soil pH was <7.

Two subsamples of soil (15 g each for 0–25 mm depth, 40 g each for 25–75 mm depth, and 60 g each for 75–150 mm and 150–300 mm depths) from each experimental unit (i.e., paddock × distance × depth combination) were wetted to 50% water-filled pore space (Franzluebbers, 1999a), placed into a 1-L canning jar along with vials containing 10 mL of 1 *M* NaOH to trap evolved CO_2 and water to maintain humidity, and incubated at 25 ± 1°C for 24 d to determine potential C mineralization (Franzluebbers and Arshad, 1996). Alkali traps were replaced at 3 and 10 d. Evolved CO_2 was calculated by titrating alkali with 1 *M* HCl to a phenolphthalein endpoint. Basal soil respiration was calculated as the linear rate of respiration from 10 to 24 d of incubation and represented an estimate of potential microbial activity. At 10 d of incubation, one of the subsamples was removed, fumigated for 24 h with

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[1]Trade and company names are included for the benefit of the reader and do not imply any endorsement or preferential treatment of the product listed by the USDA.

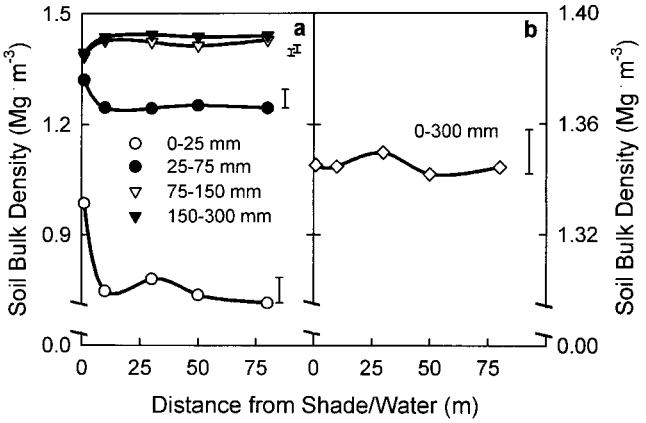

Fig. 1. Soil bulk density (a) as affected by depth and (b) averaged across depths in response to distance from shade or water sources. Error bars are LSD at $P \leq 0.05$ within a soil depth.

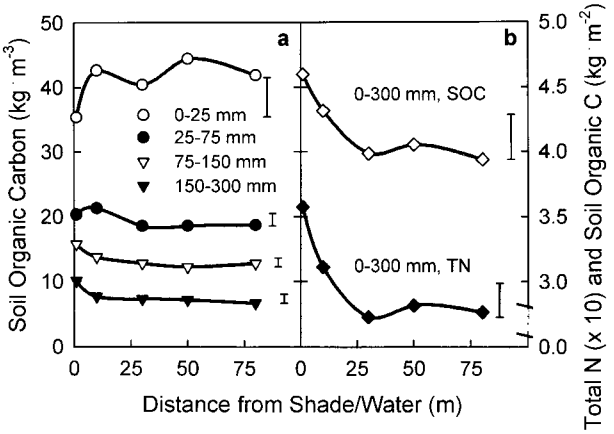

Fig. 2. Soil organic C (a) as affected by depth and (b) soil organic C and total N averaged across depths in response to distance from shade or water sources. Error bars are LSD at $P \leq 0.05$ within a soil depth.

$CHCl_3$, aerated, placed into a separate canning jar along with alkali and water, and incubated for 10 d at 25°C. Soil microbial biomass C was calculated from the quantity of CO_2 evolved during 10 d following fumigation divided by an efficiency factor of 0.41 (Voroney and Paul, 1984). Determination of soil microbial biomass C following rewetting of dried soil with 10 d of preincubation has been shown to yield estimates equivalent with those from field-moist soil (Franzluebbers et al., 1996; Franzluebbers, 1999b).

Net potential N mineralization was determined from the difference in inorganic N concentration between 0 and 24 d of incubation. Inorganic N (NH_4–N + NO_2–N + NO_3–N) was determined from the filtered extract of a 10-g subsample of oven-dried (55°C, 48 h) and sieved (<2 mm) soil shaken with 20 mL of 2 *M* KCl for 30 min by salicylate-nitroprusside and Cd-reduction autoanalyzer techniques (Bundy and Meisinger, 1994). Soil samples to a depth of 1.5 m in increments of 0.3 m were collected at the same time as surface samples for inorganic N analyses only.

Particulate organic C and N were determined by shaking the oven-dried (55°C, 72 h) fumigated sample previously used for microbial biomass determination with 0.01 *M* $Na_4P_2O_7$ for 16 h, collecting the sand plus organic matter retained on a 0.06 mm screen, oven drying (55°C, 72 h), weighing, grinding to a fine powder, and determining the C and N concentration by dry combustion as described previously (Cambardella and Elliott, 1992).

Analysis of variance was used to test the significance of difference in soil C and N pools as a function of distance from shade or water sources at (i) each depth and (ii) across depths as a standing stock weighted by volume and bulk density using SAS (SAS Institute, 1990). Values were blocked according to replicate paddock, stand age, fertilization, and endophyte infection. None of the variables had significant endophyte infection × distance interactions, and only a few variables had significant fertilization × distance interactions, which were due to greater levels under high fertilization at 10 and 50 m than under low fertilization, but similar levels between fertilization regimes at other distances. We report spatial distribution patterns averaged across management systems. Management effects of fertilization and endophyte infection on soil biochemical properties in this experiment have been reported in Schnabel et al. (2000) and Franzluebbers et al. (1999), respectively. Differences were considered significant at $P \leq 0.05$.

RESULTS AND DISCUSSION

Soil bulk densities at depths of 0 to 25 and 25 to 75 mm were 32 and 6% greater, respectively, at 1 m than at all other distances from shade or water sources (Fig. 1a). A reversal in this effect occurred at lower depths, where bulk density averaged 3% lower at 1 m than at other distances from shade or water sources at depths of 75 to 150 and 150 to 300 mm. Therefore to a depth of 300 mm, these depth-dependent changes in bulk density as a function of distance from shade or water canceled each other, resulting in no net effect of distance from shade or water sources (Fig. 1b). The least significant difference of 0.04 Mg m^{-3} indicated that our sampling procedure was sensitive enough to determine practical changes in compaction due to animal traffic. More frequent cattle traffic and destruction of vegetation immediately adjacent to shade and water sources were likely causes of surface (i.e., 0–75 mm) compaction of soil.

Soil organic C averaged 16% lower at 1 m than at other distances from shade or water sources at a depth of 0 to 25 mm (Fig. 2a). However, at a depth of 25 to 75 mm, soil organic C averaged 12% greater at 1 and 10 m than farther from shade or water sources. At depths of 75 to 150 and 150 to 300 mm, soil organic C at 1 m averaged 22 and 40% greater, respectively, than at other distances from shade or water sources. The difference in soil organic C at 1 m compared with other distances may have been, in part, due to addition of topsoil to this excreta-enriched area needed periodically to fill wallows immediately adjacent to shade and water. However, significantly greater soil organic C and N (Fig. 2b) at 10 m than at farther distances from shade or water sources indicate that this intermediate zone, which did not have wallows, was enriched by greater fecal deposition or plant growth. In a 5-yr grazing study of tall fescue in Iowa, soil organic C and N were also higher within 10 m of a water source compared with the remainder of the paddock in one of two paddocks studied (West et al., 1989). Similar to our observations, West et al. (1989) observed that grass in the zone of

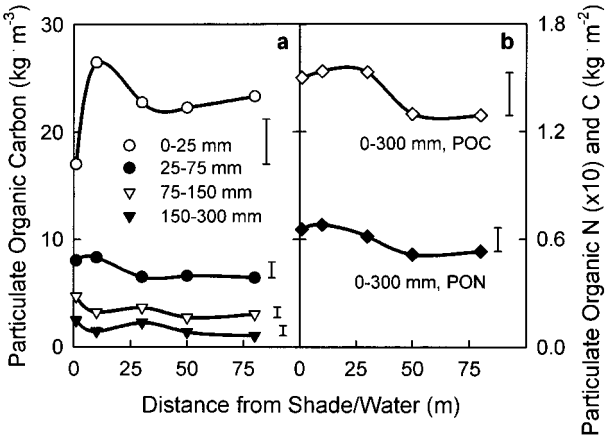

Fig. 3. Particulate organic C (a) as affected by depth and (b) particulate organic C and N averaged across depths in response to distance from shade or water sources. Error bars are LSD at $P \leq 0.05$ within a soil depth.

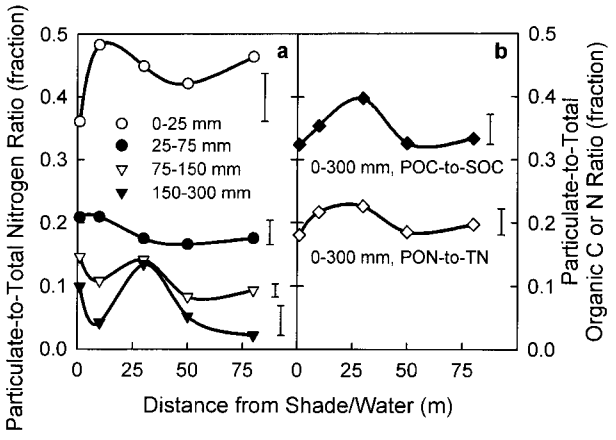

Fig. 4. Particulate organic N/total N ratio (a) as affected by depth and (b) particulate/soil organic C and N averaged across depths in response to distance from shade or water sources. Error bars are LSD at $P \leq 0.05$ within a soil depth.

enriched soil organic C (i.e., 0–10 m) was not grazed as closely as in the remainder of the paddock, perhaps because of an aversion by cattle to grazing urine- and dung-affected herbage.

Particulate organic C at 1 and 10 m from shade or water was 26% greater than at farther distances at depths of 25 to 75, 75 to 150, and 150 to 300 mm (Fig. 3a). To a depth of 300 mm, particulate organic C and N were greatest near shade or water and gradually decreased farther away (Fig. 3b). However, even at 30 m from shade or water, particulate organic C was greater ($P = 0.06$) than at either 50 or 80 m. A potential difference in source of soil organic C at 1 and 10 m from shade or water is supported by greater particulate organic C at a depth of 0 to 25 mm at 10 m than at 1 m (Fig. 3a). Particulate organic C and N are physically defined fractions of partially decomposed organic matter derived from animal and plant tissues (Cambardella and Elliott, 1992) and may be sensitive to long-term changes in surface residue accumulation and root distribution.

The ratios of particulate organic C to soil organic C and particulate organic N to total N were even more sensitive to spatial distribution than any of these individual properties (Fig. 4). Our results indicate that the 10- to 30-m distance from shade or water sources is an enriched zone of particulate organic C and N, which were probably derived from fecal deposition at the soil surface and enhanced plant root development at lower depths because of the impact of the particulate organic fraction on increased (i) supply of organic nutrients, (ii) water retention, and (iii) water infiltration.

Soil microbial biomass C at 10 m from shade or water sources was an average of 29% greater than at distances farther away at a depth of 0 to 25 mm (Fig. 5a). Comparing 1 and 10 m with 30 to 80 m from shade or water sources, soil microbial biomass C was 29% greater at a depth of 25 to 75 mm, 10% greater ($P = 0.09$) at a depth of 75 to 150 mm, and not different at a depth of 150 to 300 mm. Microbial enrichment of soil as affected by cattle drinking and lounging activity was, therefore, limited to the surface 150 mm. To a depth of 300 mm, microbial enrichment of soil was detectable near shade and water due to cattle drinking and lounging activity, with a gradual decline and reaching a trough farther away (Fig. 5b).

Basal soil respiration had a spatial distribution pattern very similar to that of soil microbial biomass C (data not shown). In fact, no difference in spatial distribution was observed in the ratio of basal soil respiration to soil microbial biomass C. This ratio, also referred to as specific microbial activity, decreased with soil depth from 33 mg g^{-1} d^{-1} (0–25 mm) to 28 mg g^{-1} d^{-1} (25–75 mm) to 19 mg g^{-1} d^{-1} (75–150 mm) to 11 mg g^{-1} d^{-1} (150–300 mm). Decreasing specific microbial activity with soil depth reflects the importance of a continuous supply of surface organic inputs, such as plant litter and feces, to support biological activity rather than a large microbial biomass. Plant residues and animal manures have been shown to be important substrates for enhancing biological soil quality in the short and long term (Fauci and Dick, 1994).

Soil inorganic N was greatest immediately adjacent to shade or water sources and decreased dramatically farther away at all soil depths (Fig. 6a). At a depth of 0 to 300 mm, inorganic N content was 147, 66, 52, 55,

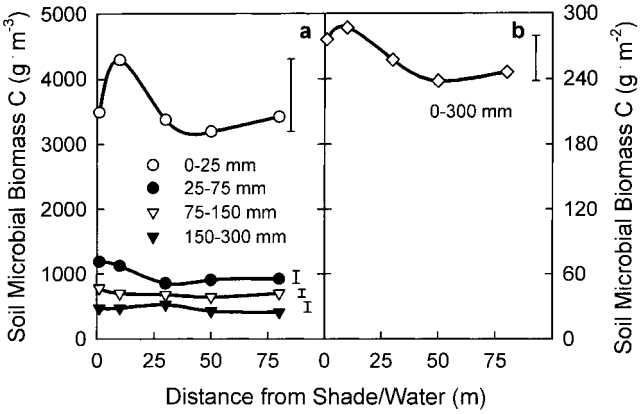

Fig. 5. Soil microbial biomass C (a) as affected by depth and (b) averaged across depths in response to distance from shade or water sources. Error bars are LSD at $P \leq 0.05$ within a soil depth.

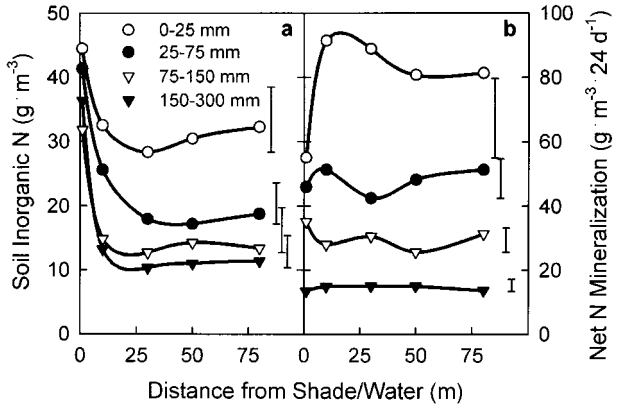

Fig. 6. Soil (a) inorganic N and (b) net potential N mineralization as affected by depth in response to distance from shade or water sources. Error bars are LSD at $P \leq 0.05$ within a soil depth.

and 56 kg N ha^{-1} at distances of 1, 10, 30, 50, and 80 m, respectively. At a depth of 300 to 900 mm, inorganic N content was 132, 53, 43, 31, and 36 kg N ha^{-1} at distances of 1, 10, 30, 50, and 80 m, respectively. At a depth of 900 to 1500 mm, inorganic N content was 139, 114, 80, 83, and 90 kg N ha^{-1} at distances of 1, 10, 30, 50, and 80 m, respectively. Considering the entire profile, inorganic N content followed the order: 1 m > 10 m > 30 m = 50 m = 80 m. Inorganic N concentration averaged across distances from shade or water was high at the soil surface, decreased rapidly to a depth of 300 to 600 mm, and then increased with further increases in depth, especially with high N fertilization (Fig. 7). It appears that tall fescue root activity may be limited to the upper 1000 mm of soil, leaving a significant quantity of inorganic N below this depth as a result of leachate accumulation. We did not discriminate between water-soluble and anion-exchangeable NO_3–N, but anion-exchange capacity is significant in these clayey subsoils (Bellini et al., 1996). The percentage of inorganic N composed of NO_3–N increased with soil depth from 26% (0–300 mm) to 71% (300–900 mm) to 83% (900–1500 mm).

The significantly higher inorganic N content nearest shade or water does not appear to have been a result of increased mineralization from soil organic N, because net potential N mineralization was lower at 1 m than other distances at a depth of 0 to 25 mm and not different from other distances at depths of 25 to 75 and 150 to 300 mm (Fig. 6b). To a depth of 300 mm, net potential N mineralization was not affected by distance from shade or water sources. Rather, higher inorganic N content nearest shade or water may have been more likely due to frequent urination and lack of vegetation immediately adjacent to shade and water. Extreme trampling of these areas led to wallows, which then had no uptake mechanism for removal of inorganic N, unlike the heavy demand for inorganic N by tall fescue forage in other areas of the paddock. An accumulation of inorganic N immediately adjacent to shade and water could lead to a potential point source that would be susceptible to leaching or gaseous losses to the environment.

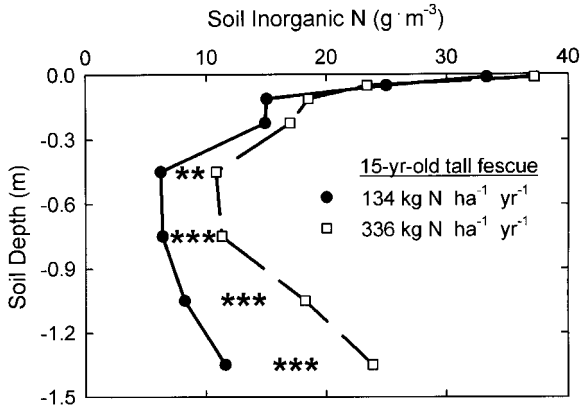

Fig. 7. Soil inorganic N as affected by soil depth and fertilization level. **, * Significant at the 0.01 and 0.001 levels of probability, respectively.**

SUMMARY AND CONCLUSIONS

In the long term, position of shade and water sources for grazing cattle can influence the spatial distribution of soil biochemical properties, including soil organic C and N, particulate organic C and N, microbial biomass C, basal soil respiration, and net potential N mineralization. The zone within a 30-m radius of shade and water sources becomes enriched in active (i.e., soil microbial biomass and readily mineralizable), slow (i.e., particulate organic), and total pools of soil C and N probably because of the high frequency of organic deposition from cattle defecation and urination, which increase fertility and subsequent forage growth. More frequent cattle traffic near shade and water sources compacted soil only to a depth of 75 mm, but did not significantly compact soil to a depth of 300 mm. To minimize the probability of N contamination of surface and groundwater supplies, shade or water sources should be (i) moved periodically to avoid point accumulation of inorganic N, (ii) positioned on the landscape to minimize the flow of percolate or runoff directly from these areas to water supplies, or (iii) avoided during routine fertilization.

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Chemical and Biochemical Properties of Humic Substances Isolated from Forest Soils and Plant Growth

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ABSTRACT

To investigate the relationships among litter composition and ^{13}C–nuclear magnetic resonance spectra (^{13}C–NMR), we studied $\delta^{13}C$ values and biochemical activities of the humic constituents extracted from the Ah horizons of two undisturbed forest soils, located in a unique climatic area under different vegetative covers, *Pinus mugo* T. and *Pinus sylvestris* L. The two litters differed greatly in composition, while the ^{13}C–NMR spectra of the humic substances extracted from the two Ah horizons were similar. The ^{13}C–NMR spectra of the low molecular humic size (LMS) 1–2 revealed high aromatic and carboxylic contents and low aliphatic and carbohydratic ones. The total humic extracts (TQ) 1–2 and the high molecular humic size (HMS) 1–2 exhibited an opposite trend. The $\delta^{13}C$ values of the humic fractions ranged from −24.96 to −25.84‰, indicating an advanced stage of humification. The biochemical activities of the humic fractions were studied by evaluating the invertase, peroxidase, and esterase activities in *Pinus mugo* and *Pinus sylvestris* seedling roots grown in the presence of their humic matter. These forest species were differently affected by their humic substances. In particular, the *Pinus sylvestris* humic matter, endowed with a higher indoleacetic acid (IAA) content, positively influenced all the enzymes tested in *Pinus sylvestris* seedlings, while the *Pinus mugo* humic matter only increased the peroxidase activity in its seedlings. The plant species differ in their capacity to respond to biological humus activity, which is reflected in their natural distribution.

It is well known that soil humic substances can affect plant growth by behaving as growth hormones (Hillitzer, 1932; Cacco and Dell'Agnola, 1984). In many systems, humic substances behave similarly to true auxins, but until recently it had not been shown that they could contain substances similar to auxins (Vaughan and Malcolm, 1985; Nardi et al., 1996).

In a recent study, Muscolo et al. (1998) demonstrated that indoleacetic acid (IAA) is present in humic substances but its concentration is not sufficient to justify its biochemical activity in plant systems. The uncertainty regarding the mechanism by which humic substances stimulate plant biochemical activities is also in part due to the heterogeneity of humic substances and the difficulty of their characterization. Thus, attempts to relate humus structure to biochemical activity have produced contrasting results.

Mato et al. (1972) and Pflug and Ziechman (1981) found that functional carboxyl and hydroxyl groups in humic substances were related to biochemical activity. Vaughan (1967a, 1967b), Vaughan et al. (1974), and Nardi et al. (1991) established that the low molecular size (LMS) humic components are effective in enhanced plant metabolism. On the other hand, Ladd and Butler (1971), Malcolm and Vaughan (1979), and Nardi et al. (1991) found that high molecular size (HMS) humic components appeared to be similarly active.

In natural soils, humic constituents characterized as LMS are embedded in macro structures with HMS. The disassociation of the HMS and LMS structures within the root–soil surface is controlled by the organic acids present in exudates (Nardi et al., 1996; Tan, 1998).

In forest soils, the separation between HMS fractions with lower biological activity and LMS with biological activity is not as evident as it appears in arable soils

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Abbreviations: ELISA, enzyme-linked immuno–sorbent assay; GA, gibberellic acid; HMS, high molecular humic size; IAA, indoleacetic acid; LMS, low molecular humic size; NMR, nuclear magnetic resonance; TQ, total humic extract.